

Tracking trends in the extinction risk of wild relatives of domesticated species to assess progress against global biodiversity targets

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Funding information

Newcastle University, UK; Biodiversity Indicators Partnership

Abstract

Ensuring the conservation of wild relatives of domesticated animals that are important food sources for humans forms part of targets for both the Convention on Biological Diversity (CBD) and the Sustainable Development Goals (SDG). There is, however, no indicator allowing progress toward these aims to be measured. We identified 30 domesticated mammal and bird taxa that are sources of food for humans and consider 55 mammal and 449 bird species to be their wild relatives. We developed a Red List Index for these wild relatives, which declined by 2.02% between 1988 and 2016. Currently, 15 species are Critically Endangered, indicating that the Red List Index could deteriorate sharply unless action is taken to ensure the survival of highly threatened species and the reversal of their declines. This Index can meet a range of global policy needs, including reporting on progress toward Aichi Target 13 of the Strategic Plan for Biodiversity 2011–2020 and SDG Target 2.5.

KEY WORDS

Aichi Biodiversity Targets, biodiversity indicator, Convention on Biological Diversity, extinction probability, food security, livestock, Red List Index, Sustainable Development Goals, Target 13, World's Animal Genetic Resources

1 | INTRODUCTION

In 2010, the 193 Parties to the Convention on Biological Diversity adopted 20 targets as part of the Strategic Plan for Biodiversity 2011–2020. These 20 “Aichi Targets” were considered an ambitious strategic approach to biodiversity conservation, recognizing that biodiversity underpins ecosystem services that are necessary for human wellbeing, including food security and human health (CBD, 2010). Aichi Target 13 is concerned specifically with species that are important to people and that, therefore, provide important ecosystem services, such as food, cultural services, and other social and economic services. The target, in full is:

“By 2020, the genetic diversity of cultivated plants and farmed and domesticated animals and of wild relatives, including other socio-economically as well as culturally valuable species, is maintained, and strategies have been developed and implemented for minimizing genetic erosion and safeguarding their genetic diversity.” (CBD, 2010).

Similarly, Sustainable Development Goal (SDG) 2.5 commits countries to “By 2020, maintain the genetic diversity of seeds, cultivated plants and farmed and domesticated animals and their related wild species, including through soundly managed and diversified seed and plant banks at the national, regional, and international levels, and promote access to and fair and equitable sharing of benefits arising from the utilization of genetic resources and associated traditional knowledge, as internationally agreed” (United Nations, 2015).

At present, there is only one indicator available for these targets: “the proportion of local breeds classified as being at risk, not-at-risk or at unknown level of risk of extinction” (Secretariat of the Convention on Biological Diversity, 2014; Tittensor et al., 2014). Additional potential indicators have been identified (CBD, 2016; United Nations, 2016), but none have hitherto been implemented.

These targets are complex, and cover a range of different types of species, as well as processes and outcomes for their conservation. The existing indicator is concerned solely with local breeds of farmed animals, and doesn't address the status of wild species that are important to humans, whether as wild relatives of domesticated species or because of their direct relationship with humans, in culture or as a result of other socio-economic uses and relationships.

It is a considerable challenge to understand the diversity of relationships that humans have with species. The importance and benefits of species in a variety of contexts has been outlined by Gascon et al. (2015), who indicated that cultural

ecosystem services are “notoriously hard to measure.” Furthermore, they suggest that these services change over time and the range of contexts in which species can be considered to play a cultural service to people is increasingly diverse. For example, while the concept of “cultural keystone species” (see Cristancho & Vining, 2004; Garibaldi & Turner, 2004) is typically considered within the context of human communities that live alongside the species that is of especial importance, Gascon et al. (2015) offer examples where the service is provided to people who live at some distance from the species, through social and other media. There is also a range of species that have been domesticated for nonfood purposes, such as pets. All of this means that developing an indicative list of wild species that may be an appropriate indicator suite for that part of Target 13 remains a considerable challenge.

It is more tractable to identify “farmed and domesticated animals” and then to identify their wild relatives. Few data, however, exist on the genetic diversity of wild bird and mammal species (Evans & Sheldon, 2008; Garner, Rachlow, & Hicks, 2005). Pimm and Jenkins (2010) noted that genetic diversity is known for too few species to allow it to provide a measure of diversity at a large scale. Recent global analyses of publicly available genetic sequences revealed substantial spatial and taxonomic data gaps (Gratton et al., 2017; Miraldo et al., 2016) and, moreover, these snapshot studies were not able to consider temporal changes. There is, however, a relationship between genetic diversity and extinction risk (see Mace et al., 2008). Given that it is not currently practical to measure trends in genetic diversity of wild species at a global or regional scale, it is therefore reasonable to use the Red List Index as a surrogate for trends in genetic diversity.

The Red List Index (RLI) uses data from the IUCN Red List of Threatened Species, which is widely considered to be the most authoritative and objective system for categorizing the extinction risk of taxa (de Grammont & Cuarón 2006). Species are assigned to categories of extinction risk (ranging from Least Concern to Critically Endangered and Extinct) using criteria with quantitative thresholds for population size, decline, and distribution size (IUCN, 2012). The RLI shows trends over time in survival probability (the inverse of extinction risk) (Butchart et al., 2004, 2007). The index is based on the proportion of species that move through the IUCN Red List categories between periodic assessments, either away from or toward extinction, as a result of genuine improvement or deterioration in status. It excludes category changes resulting from taxonomic revisions or improvements in knowledge (Butchart et al., 2004, 2005, 2007). Global RLIs have

been calculated for all birds (BirdLife International, 2013; Butchart et al., 2004, 2010; Hoffmann et al., 2010), mammals (Hoffmann et al., 2010, 2011), amphibians (Hoffmann et al., 2010; Stuart et al., 2004), reef-building corals (Butchart et al., 2010), and cycads (UN, 2017), with thematic disaggregations for pollinators (Regan et al., 2015), and showing the net impacts of different drivers (McGeoch et al., 2010; Tittensor et al., 2014).

We therefore calculated an RLI for wild relatives of farmed and domesticated (hereafter, collectively referred to as “domesticated”) animals, as recommended by CBD (2016), to support tracking of progress toward Aichi Target 13 and SDG 2.5. We focused on the wild relatives of farmed and domesticated birds and mammals only, and did not consider the wild relatives of farmed fish or cultivated plants, as too few of the latter have been assessed for the IUCN Red List more than once.

2 | METHODS

To produce the RLI, we

1. Identified bird and mammal taxa that have been “domesticated” for food;
2. Identified the wild relatives of these taxa; and
3. Calculated a Red List Index for these wild relatives using data from the IUCN Red List.

2.1 | Domesticated species

The domestication of animals is an evolutionary process without a definitive end point (Larson & Burger, 2013); therefore determining when an animal can be considered “domesticated” is somewhat subjective. In order to compile a list of domesticated species as objectively as possible we included only taxa that were considered as domesticated and that were used, at least in some instances, for food according to the 1st and 2nd reports on the *State of the World's Animal Genetic Resources for Food and Agriculture* from the Food and Agriculture Organization of the United Nations (FAO, 2007, 2015). We matched the taxonomy and nomenclature of these reports to those for the ancestor taxa from the IUCN Red List. The majority of domestic derivatives share the same scientific name as their wild progenitors, however in some cases there are separate names, and for these the FAO observes the nomenclature presented by the International Commission on Zoological Nomenclature (2003). This gave a list of 19 mammalian and 11 avian domesticated taxa (Table 1).

2.2 | Wild relatives of domestic species

For crop species, wild relatives are determined based on taxonomic relatedness; all wild species within the same genus

as the domesticated species are considered to be relatives (Maxted, Ford-Lloyd, Jury, Kell, & Scholten, 2006). However, there is as yet no translation of this definition to domesticated animals. In terms of the potential genetic contribution of wild relatives to domesticated species, the key consideration is the potential ability of domesticated species to breed with wild relatives. There is no detailed analysis across all of these domesticated species about which wild relatives that they can breed with, and produce fertile offspring. We therefore not only considered wild species within the same genus as domesticated species, but also included any taxa in other genera that had documented evidence of hybridization with the domesticated species (see Supplementary Information for more details).

2.3 | Calculating a Red List Index of wild relatives of domesticated species

We calculated the RLI using assessments from between 1988 and 2016 for birds, and 1996 and 2008 for mammals, following Butchart et al. (2007). The number of species in a Red List category in a particular year was multiplied by a weight (ranging from 0 for Least Concern to 5 for Extinct), with the scores summed and expressed as a fraction of the maximum possible sum (if all species had gone Extinct). The number of species in each category for years prior to the most recent assessment were calculated based on the number of species that qualified for genuine IUCN Red List category changes in each time period between assessments (i.e., excluding changes owing to improved knowledge or taxonomic revision), updated from those given in Hoffmann et al. (2010). Following Butchart et al. (2010), we calculated an RLI for each group separately, interpolating indices linearly for years between data points, and calculated an aggregated RLI as the arithmetic mean of the two modeled RLIs. The index for mammals was extrapolated linearly back to 1988 and forward to 2016 (the years of first and last assessment for birds), following Butchart et al. (2010). A 95% confidence interval was calculated using a bootstrapping approach in order to account for the uncertainty introduced by extrapolation and by temporal variability in the “true” RLI in the periods between assessments, following Butchart et al. (2010). For birds, RLIs were produced for both a conservative (Figure 1) and liberal list of wild relatives (Supporting Information Figures 1 and 2).

3 | RESULTS

3.1 | Extinction risk of wild relatives of domesticated species

Fifty-one percent of wild mammal relatives (28 out of 55 species) and 19% of wild bird relatives (86/449) are presently

TABLE 1 Domesticated animal taxa listed by FAO (2007, 2015) and the ancestor species from which they have been domesticated following the taxonomy and nomenclature of the IUCN Red List (IUCN 2017b)

Domesticated animal taxa (FAO, 2007, 2015)		Ancestor species (IUCN, 2017b)	
Common name	Scientific name	Common name	Scientific name
MAMMALIA			
Mithun	<i>Bos frontalis</i>	Gaur	<i>Bos gaurus</i>
Yak	<i>Bos grunniens</i>	Yak	<i>Bos mutus</i>
Bali cattle/Banteng	<i>Bos javanicus</i>	Banteng	<i>Bos javanicus</i>
Taurine cattle	<i>Bos taurus</i>	Auroch	<i>Bos primigenius</i> (extinct)
Zebu cattle	<i>Bos indicus</i>	Auroch	<i>Bos primigenius</i> (extinct)
River/Swamp buffalo	<i>Bubalus bubalis</i> (incl. subspecies <i>carabensis</i>)	Wild water buffalo	<i>Bubalus arnee</i>
Bactrian camel	<i>Camelus bactrianus</i>	Bactrian camel	<i>Camelus ferus</i>
Dromedary	<i>Camelus dromedarius</i>		
Dog	<i>Canis familiaris</i>	Wolf	<i>Canis lupus</i>
Goat	<i>Capra hircus</i>	Wild goat	<i>Capra aegagrus</i>
Guinea pig	<i>Cavia porcellus</i>		
Horse	<i>Equus caballus</i>	Wild horse	<i>Equus ferus</i>
Donkey	<i>Equus asinus</i>	African wild ass	<i>Equus africanus</i>
Llama	<i>Lama glama</i>	Guanaco	<i>Lama guanicoe</i>
Rabbit	<i>Oryctolagus cuniculus domesticus</i>	European rabbit	<i>Oryctolagus cuniculus</i>
Sheep	<i>Ovis aries</i>	Mouflon	<i>Ovis orientalis</i>
Reindeer	<i>Rangifer tarandus</i>	Reindeer/caribou	<i>Rangifer tarandus</i>
Pig	<i>Sus domesticus</i>	Wild boar	<i>Sus scrofa</i>
Alpaca	<i>Vicugna pacos</i>	Vicuna	<i>Vicugna vicugna</i>
AVES			
Domestic duck	<i>Anas platyrhynchos</i>	Mallard	<i>Anas platyrhynchos</i>
Goose	<i>Anser anser</i>	Greylag Goose	<i>Anser anser</i>
Chinese goose	<i>Anser cygnoides</i>	Swan Goose	<i>Anser cygnoid</i>
Muscovy duck	<i>Cairina moschata</i>	Muscovy Duck	<i>Cairina moschata</i>
Pigeon	<i>Columba livia</i>	Rock Dove	<i>Columba livia</i>
Quail	<i>Coturnix japonica</i>	Japanese Quail	<i>Coturnix japonica</i>
Chicken	<i>Gallus domesticus</i>	Red Junglefowl	<i>Gallus gallus</i>
Turkey	<i>Meleagris gallopavo</i>	Wild Turkey	<i>Meleagris gallopavo</i>
Guinea fowl	<i>Numida meleagris</i>	Helmeted Guineafowl	<i>Numida meleagris</i>
Pheasant	<i>Phasianus colchicus</i>	Common Pheasant	<i>Phasianus colchicus</i>
Ostrich	<i>Struthio camelus</i>	Common Ostrich	<i>Struthio camelus</i>

considered threatened (i.e. in the categories of Critically Endangered, Endangered, and Vulnerable). This includes seven Critically Endangered mammal species and eight Critically Endangered bird species (Table 2). Under a more liberal definition of wild relatives, 21% of bird species (154/734) are considered threatened, of which 23 are Critically Endangered (Supporting Information Table 4).

All mammal species have been assessed for the IUCN Red List twice: in 1996 and 2008. During this period, 12 species of wild relatives underwent changes in status (population size, rate of decline, range size etc.) that were of sufficient magnitude to qualify for a higher or lower Red List category of extinction risk. Seven species qualified for uplisting to

higher risk categories because they deteriorated in status. For example, Tamaraw *Bubalus mindorensis*, a dwarf buffalo species endemic to Mindoro in the Philippines, qualified for uplisting from Endangered to Critically Endangered because the loss of some subpopulations during 1996–2008 meant that the largest subpopulation contained over 95% of the global population, qualifying the species as Critically Endangered under criteria C1+C2a(ii) (Boyles, Schutz, & de Leon, 2016; Hoffmann et al., 2010). Conversely, five species improved in status sufficiently owing to conservation action that they qualified for downlisting to a lower category of threat. For example, Przewalski's Horse *Equus ferus*, which was last seen in the wild in Mongolia in 1969, was reintroduced into the

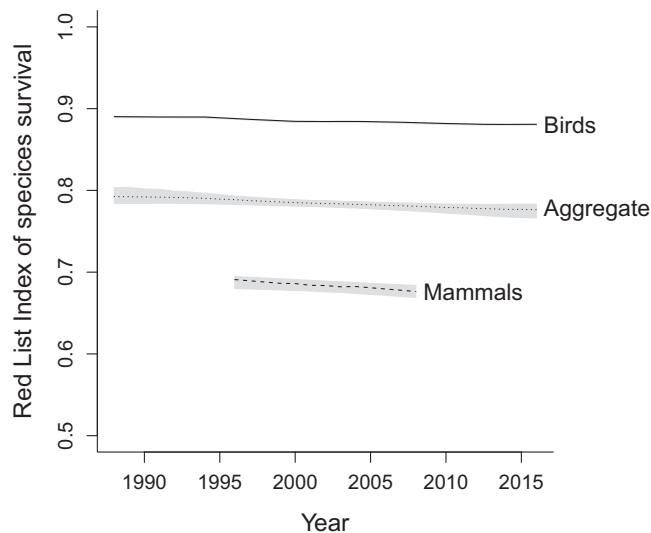


FIGURE 1 Red List Indices for wild relatives of domesticated mammal and bird species, and an aggregated index based on results for both groups. Confidence intervals are shown in gray (these are so narrow as to be barely visible for the RLI for wild relatives of domesticated bird species)

TABLE 2 Number of species in each Red List category (IUCN 2017)

Red List category	Number of species	
	Mammals	Birds
Critically endangered	7	8
Endangered	10	20
Vulnerable	11	58
Near threatened	8	60
Least concern	19	303
Total	55	449

wild from captive populations during the 1990s in Mongolia, with these individuals eventually breeding successfully and qualifying the species for downlisting from Extinct in the Wild to Critically Endangered during 1996–2004 and then to Endangered in 2011 (Hoffmann et al., 2010; King, Boyd, Zimmermann, & Kendall, 2015).

All bird species have been assessed for the IUCN Red List seven times between 1988 and 2016. During this period, 31 species of wild relatives underwent changes in status that were of sufficient magnitude to qualify for a higher or lower Red List Category (listed in Supporting Information Table 3). This includes 25 species that worsened in status and qualified for uplisting to a higher category of risk, and six species that improved in status owing to conservation action (five species) or land abandonment (one species). For example, the rate of population decline of Greater Prairie-chicken *Tympanuchus cupido* from North America is estimated to have exceeded 30% over ten years during 1988–1994 owing to habitat loss and fragmentation, qualifying the species for uplisting from

Near Threatened to Vulnerable under criterion A2 by 1994 (BirdLife International, 2017a). In contrast, Brown Teal *Anas chlorotis* populations in New Zealand have been increasing since 2003, qualifying the species for downlisting from Endangered to Near Threatened during 2000–2004 as the species no longer meets the conditions for listing as threatened under Criterion B1 (BirdLife International, 2017b). Two of the 25 species underwent declines in status and qualified for movement to higher categories in each of two time periods between Red List assessments (1994–2000 and 2004–2008 for Baer's Pochard *Aythya baeri*, and 2004–2008 and 2008–2012 for Long-tailed Duck *Clangula hyemalis*). Under a more liberal definition of wild relatives, 48 species qualified for higher (40 species) or lower (eight species) Red List Categories owing to deterioration or improvement in status respectively.

3.2 | Red List Index of wild relatives of domesticated species

The RLI for wild relatives of domesticated species shows the net impact on aggregate extinction risk of the improvements and deteriorations in status of species noted above. The index for mammals declined by 2.11% between 1996 and 2008 (0.18% per year), while the equivalent index for birds declined by 1.05% between 1988 and 2016 (0.04% per year). The aggregated index for both groups declined by 2.02% between 1988 and 2016 (0.07% per year). Mammal wild relatives are at higher risk of extinction on average than bird wild relatives (i.e. their survival probability and hence Red List Index values are lower), reflecting the pattern for mammals and birds more generally (Hoffmann et al., 2010).

The results for birds using a more liberal definition of wild relatives showed similar results (1.12% decline between 1988 and 2016, equating to 0.04% per year), with slightly higher RLI values on average (i.e. marginally lower extinction risk) (Supporting Information Figures 1 and 2).

4 | DISCUSSION

The RLI for wild relatives of domesticated birds and mammals that are important food sources for humans declined by 2.02% between 1988 and 2016 (0.07% per year), and wild mammal relatives have a higher overall probability of extinction than wild bird relatives. Wild relatives of domesticated mammals and birds have a higher overall probability of extinction than all mammals and all birds, respectively (53% and 31% of mammal and bird wild relatives are threatened, compared with 25% and 13% for all mammal and bird species, respectively, IUCN, 2017a), leading to them having lower RLI values (i.e. greater risk of extinction) than those for all birds and mammals, respectively (IUCN, 2017b).

Considering Aichi Target 13, therefore, not only is the conservation status of wild relatives of domesticated mammals and birds deteriorating, but these species are, overall, more threatened than all birds and all mammals. This means that CBD Parties are currently not on track to meet the relevant components of Aichi Target 13 and Sustainable Development Goal 2.5. Furthermore, 15 species are Critically Endangered, indicating that they face “an extremely high risk of extinction in the wild” and a further 30 species are Endangered, representing “a very high risk of extinction in the wild” (IUCN, 2012). This indicates that the RLI could deteriorate sharply unless action is taken to ensure the survival of these highly threatened species and the reversal of their declines.

This finding is important because these species contain genetic diversity that may allow the development of more productive, nutritious, and resilient livestock breeds (see Castañeda-Álvarez, Khoury, & Achicanoy, 2016), which is significant given the likely impacts of global change on the animal populations we rely on for food (see IPCC, 2007). Livestock species provide 25% of dietary protein (FAO, 2009) and it is important, therefore, to ensure the conservation of the closest wild species to these domesticated forms so as to ensure long-term food security for a significant proportion of the world's population. Genetic diversity cannot currently be measured directly using available data for these species, and so this indicator provides the most practical proxy, although it may hide declines in genetic diversity among subspecies. The list of wild relatives included in the indicator could be revised when further evidence of the fertility of hybrids across the species included becomes available. The indicator could also be extended to include wild relatives of other domesticated species (e.g. pets) and “other socio-economically as well as culturally valuable species” (another component of Aichi Target 13), should such species be identified in a systematic and repeatable way. Until that time, the method that we apply for identifying wild relatives is consistent and reproducible.

This version of the RLI can meet various policy needs. The first Global Assessment of the Intergovernmental Science-Policy Platform for Biodiversity and Ecosystem Services (IPBES) is currently under development and will be published in May 2019. It includes a chapter that assesses progress toward the Aichi Targets and relevant SDGs, for which the RLI for wild relatives of domesticated species can contribute to assessment of progress toward Aichi Target 13 and SDG 2.5. The IPBES Global Assessment will in turn form part of the basis of the Fifth Global Biodiversity Outlook, to be released by the CBD in 2020, in which it will be reported whether the world met the Aichi Targets or not. This report will also set the background to the adoption of a new strategic plan on biodiversity for the next decade. Finally, the indicators for the SDGs will next be reviewed in 2020, when consideration can be given to adopting the RLI for wild relatives of domesticated species to report on progress to SDG 2.5.

The indices presented here will be updated in step with publication of updates to the IUCN Red List. Importantly, all mammal species will be reassessed in 2018, with the next comprehensive assessment for birds scheduled for 2020. The most important future development would be to integrate comparable data for wild relatives of cultivated crops. IUCN has identified as a top priority the need to complete assessments for c. 1500 selected crop wild relatives by 2020 (IUCN Red List Committee, 2013), and this is the main focus for a dedicated “Crop Wild Relatives Specialist Group” of the IUCN Species Survival Commission. The subsequent reassessment of these species would allow the first RLI for this group of species to be calculated, which will complement and can be combined with the one for wild relatives of domesticated animal species presented here.

ACKNOWLEDGMENTS

We thank the many thousands of individuals and organizations who contribute to the periodic assessment of all birds and mammals on the IUCN Red List. We thank John P. Carroll (IUCN SSC Galliformes Specialist Group), Tom Lacher (IUCN SSC Small Mammal Specialist Group) and Sandro Lovari and Juan Herrero (IUCN SSC Caprinae Specialist Group) for their input on identifying wild relatives and for comments on the manuscript. The work was supported by the Biodiversity Indicators Partnership and Newcastle University.

CONFLICT OF INTEREST

The authors have declared no conflict of interest.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

How to cite this article: McGowan PJK, Mair L, Symes A, et al. Tracking trends in the extinction risk of wild relatives of domesticated species to assess progress against global biodiversity targets. *Conservation Letters*. 2018;e12588. <https://doi.org/10.1111/conl.12588>